Cummins Westport
The Natural Choice

CWI Engine Update

Natural Gas Vehicle Technology Forum

October 15, 2014

Stephen Ptucha

Product Management & Planning
Cummins Westport Inc.

ISB6.7 G Project Introduction

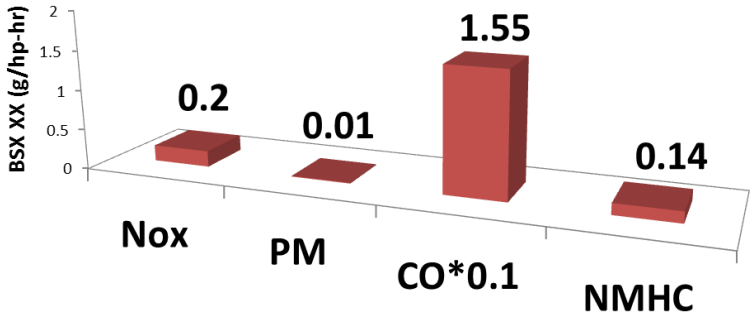
- Cummins Westport (CWI) and Gas Technology Institute (GTI) were awarded $1M from the California Energy Commission Public Interest Energy Research (PIER) program

- Grant funding supports Alpha design, development, demonstration, and Beta design of a new, 6.7 liter natural gas engine

- Grant agreement term: Aug/13 thru Nov/14

Project Goal

- Demonstrate the performance and emissions capability of the proposed new 6.7 liter engine, targeting the following objectives with the Alpha design:
- U.S. EPA / CARB 2013 emission standards (g/bhp-hr):



- U.S. EPA 2017 GHG emission standards
  - GHG emissions (CO_2, CH_4 and N_2O)
- Peak rating of 260 hp and 660 lb-ft torque.
- 5 to 10% improved fuel economy over CWI's 5.9 liter lean burn SI NG engine (last sold in the North American market through 2009)

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System Architecture

- Same architecture as ISL G & ISX12 G, sized to ISB6.7 platform
  - Stoichiometric, cooled EGR spark ignition
  - Coil-on-plug ignition
  - 4 valve head

ISL G

ISB6.7

ISB6.7 G

Common Emissions Architecture
- Stoichiometric Combustion, Cooled EGR & Three Way Catalyst
- Control System

Common Base Engine Architecture
- Base Engine
- Cooled EGR

Pre-Alpha Design

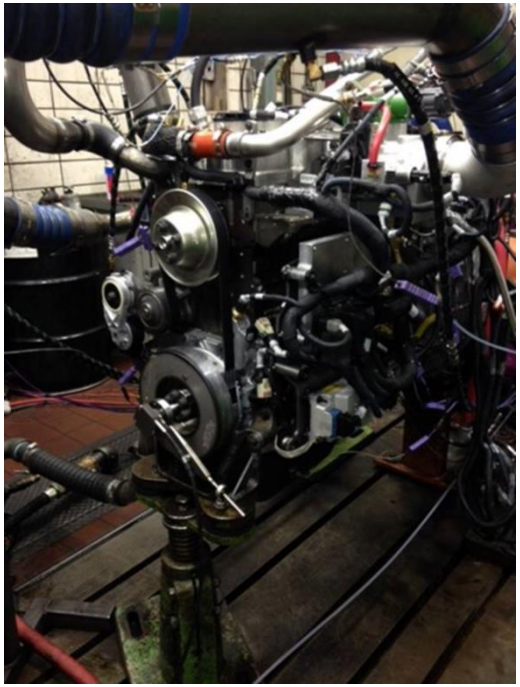
- Goals
  - Define and verify engine architecture.
  - Demonstrate target performance levels with stable operation

- Analysis tools used prior to engine build and test were:
  - DFMEA (Design Failure Mode Effects Analysis)
  - CAD layout (Pro Engineer by Parametric Technologies)
  - Engine performance model (“GT Power” by Gamma Technologies)
  - Combustion modeling (“KIVA” by Los Alamos National Lab)
  - FEA (Finite Element Analysis)
  - CFD (Computational Fluid Dynamics)

Pre-Alpha Engine Testing

- Demonstrated Engine Performance

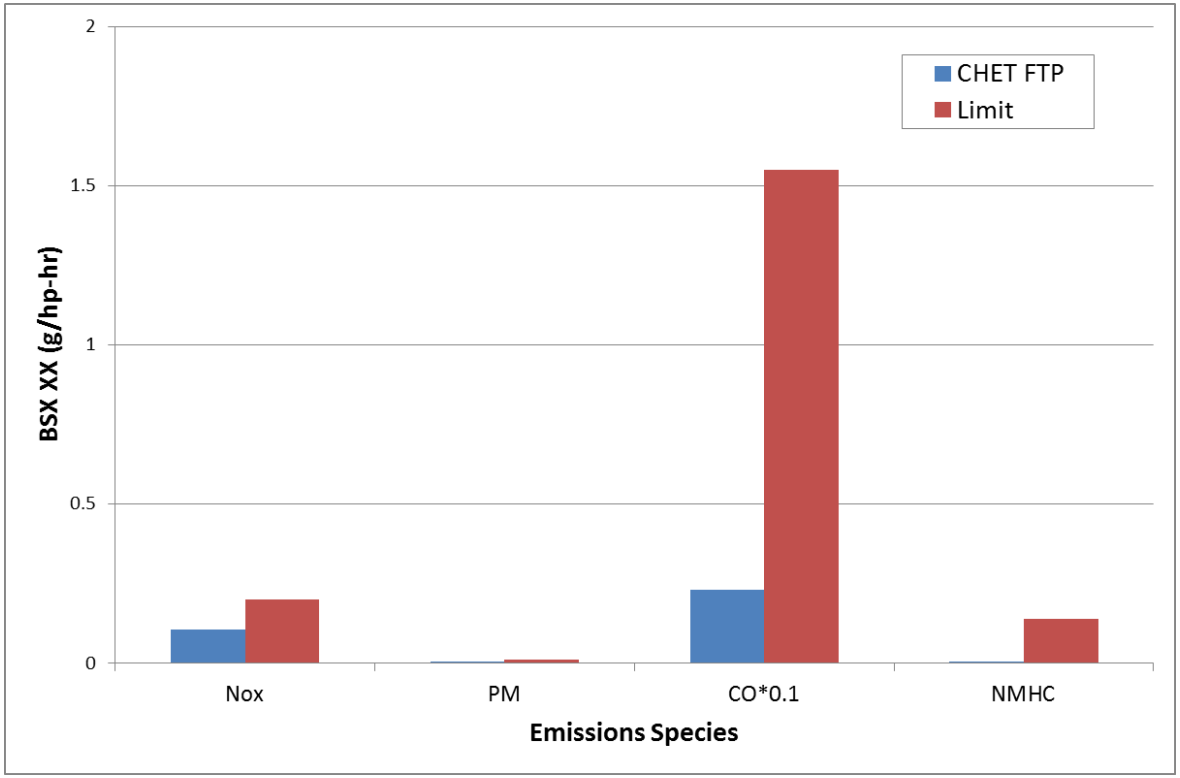
VOC DELIVERABLE	STATUS
Emissions (NOx, PM, CO, etc)	✓
Green House Gas	✓
Noise	✓
Peak Power	✓
Peak Torque	✓
Responsiveness	✓
Heat Rejection	✓
Fuel Economy	✓
Transmission Compatibility	✓



- Learnings for Alpha Design
  - Multiple piston designs tested, narrowed choice for Alpha
  - Confirmed use of existing ISL G three way catalyst

Pre-Alpha Engine Testing

- Emissions
  - Demonstrated ability to achieve regulated emissions at / below EPA / CARB 2013 standards



Alpha Design

- Goals:
  - apply the learning gained from the concept engine operation
  - begin optimizing the engine and engine component designs
  - further assess the design capability to meet targets

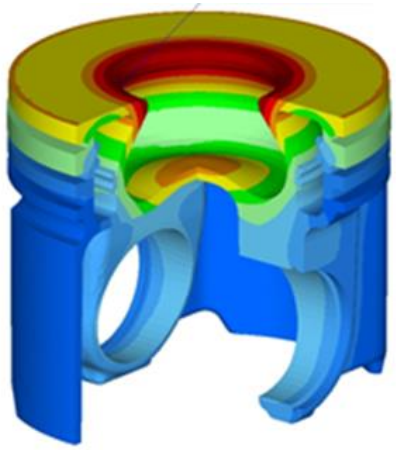
- Differences Concept / Alpha design:
  - Concept design uses existing components wherever possible
  - Alpha design strives for “production-intent” design components.
  - Alpha focuses on creating component and sub-system designs that will enable high-volume manufacturing.

Alpha Design

- Alpha design focused on the following components & subsystems
  - Power cylinder
  - Control system
  - Ignition system
  - Cylinder head
  - Air handling (i.e. turbocharger)
  - Fuel supply module
- Alpha testing
  - Engine Dynamometer testing
  - Vehicle testing

Alpha Design

- Base Engine
  - Cummins ISB6.7 diesel engine
  - Retains, cylinder block, crankshaft, connecting rods, main bearings
  - Share external accessories (air compressor, alternator, starter, etc) and customer selectable options (flywheel housing, oil pan, etc.)
- Power Cylinder
  - Unique piston design for required compression ratio, optimized for in-cylinder conditions with SI combustion and durability.
  - Piston design refined based on test data and further analytical modeling, focusing on combustion rate and component durability.

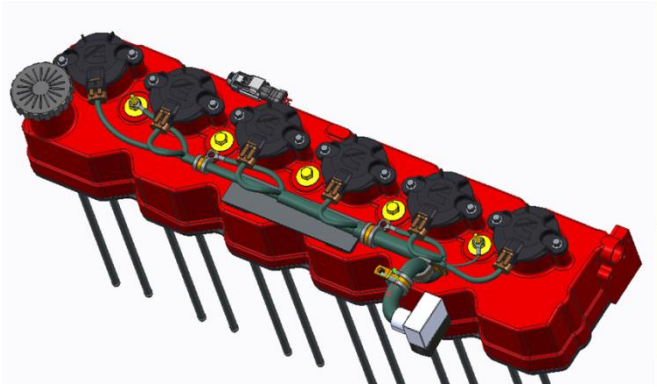


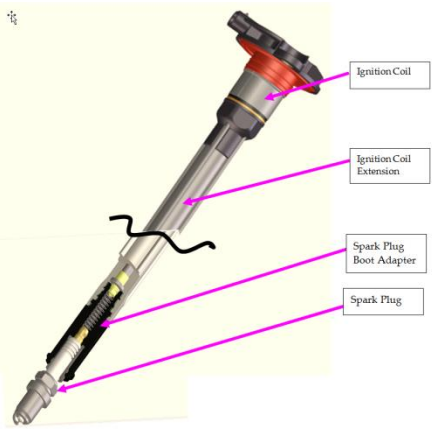
Alpha Design

- Electronic Control System
  - Direct carry-over architecture from the ISL G and ISX12 G engines.
  - Combination of shared and unique hardware
  - Unique software and calibrations required to enable certain electronic features carried over from diesel product
- Ignition System
  - Architecture identical to ISX12 G, but unique packaging

Electronic Control System
Electronic Control Module (ECM)
Sensors
Actuators
Wire Harness
Software & Calibrations

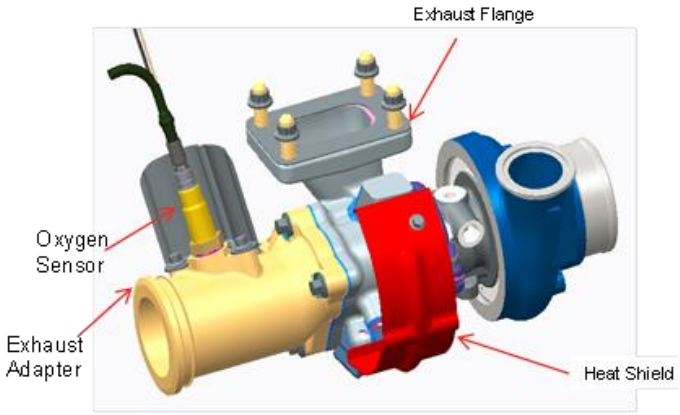
Ignition System
Ignition Control Module (ICM)
Ignition Harness
Ignition Coils
Ignition Coil Extensions
Spark Plugs
Calibration

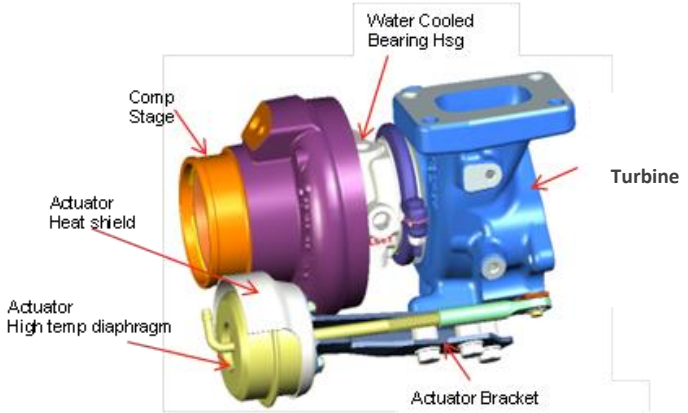




Alpha Design

- Cylinder Head & Valve Train
  - Improved thermal fatigue characteristics through shallow “scalloped” cuts in combustion face of cylinder head
  - Increased thermal fatigue strength through material change from gray iron to an alloyed iron with molybdenum
  - Spark plug bore machining will take the place of the injector bore.
  - Increased durability through high temperature valve and seat insert materials
- Air Handling System
  - Unique Turbocharger due to lower air flow requirements
  - Turbine housing material selection to improve high temperature capability.
  - Additional changes to improve robustness





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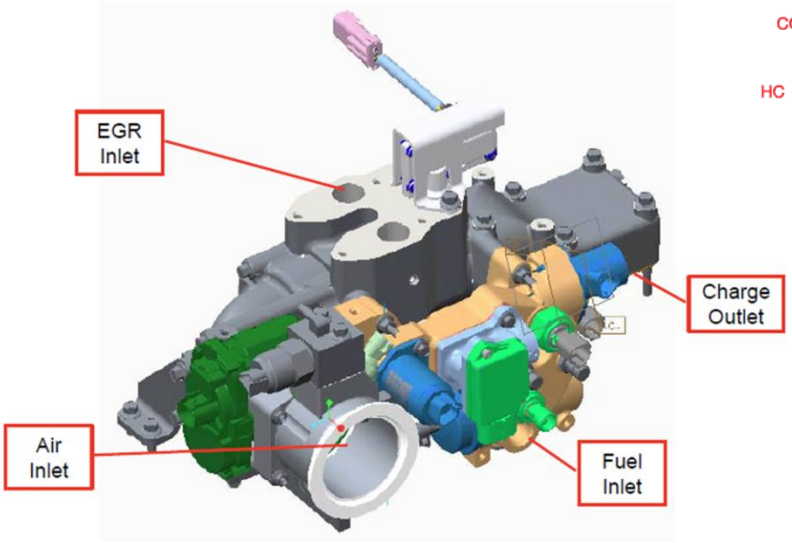
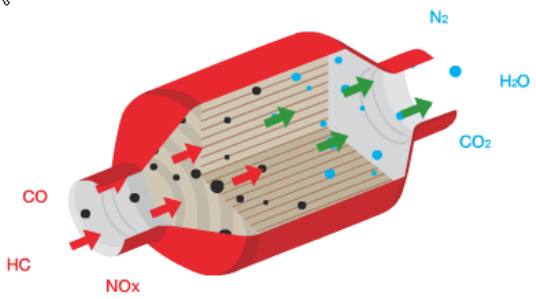
Alpha Design

- Fuel System
  - Architecturally similar to the ISL G engine:
  - Larger space claim required than diesel due to increased functional requirements.
  - Numerous design iterations in conjunction with various truck and bus OEMs.

Fuel System Function
Natural gas fuel supply
Pressure regulation
Metering and control
Charge air throttling & measurement
EGR control and mixing



- Aftertreatment
  - Three way catalyst (TWC) to treat emissions
  - Analysis & measurements confirmed ISL G TWC is an acceptable emission solution for the 6.7



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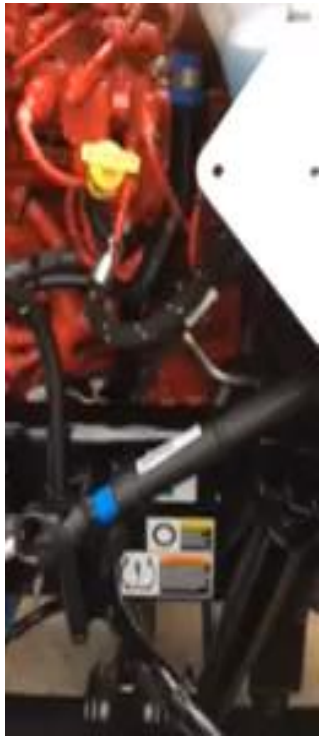
Alpha Engine Validation Testing

- Alpha Testing is well underway
  - Test cell testing of performance and durability
  - Vehicle testing for performance and customer acceptance.
- Beta engine design based on learnings form Alpha
- Nearing end of CEC funded project, with product commercialization following

- Thank you to CEC's PIER program management and staff for supporting this project.

Field Test Start-ups



Kwik Trip 2

Blue Water 1

Walmart

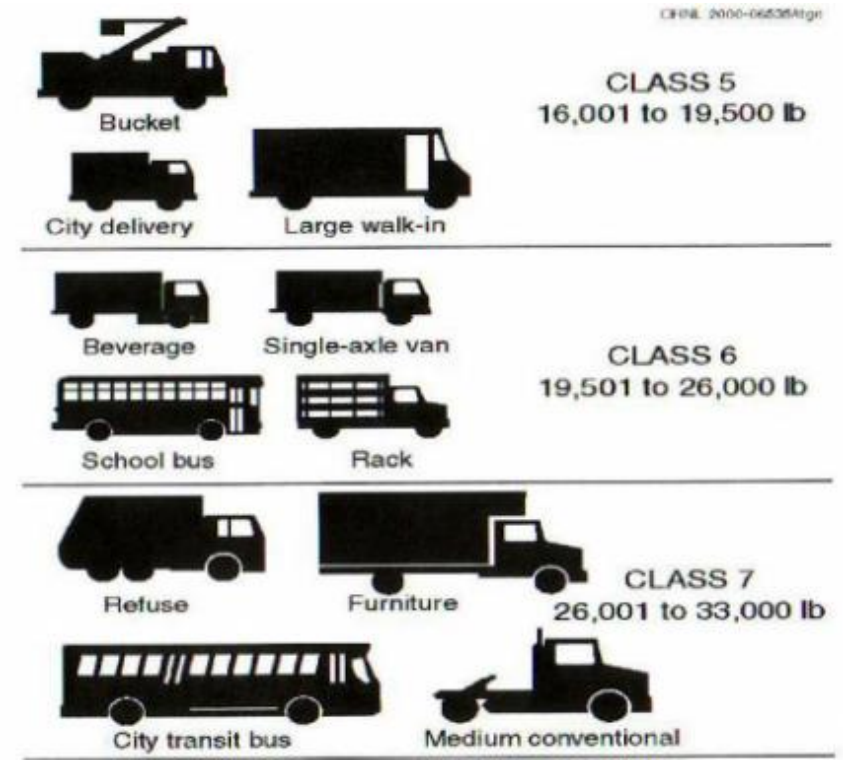
ISB6.7 G Target Markets

Medium Duty Trucks
- Pickup & delivery
- Utility
- Food and Beverage
- Flat Bed
- Dump
- Tanker

Bus
- School Bus
- Shuttle Bus

Vocational
- Street sweepers,
- Yard trucks

Delivery Vans



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ISX12 G Post Launch Update

Natural Gas Vehicle Technology Forum

October 15, 2014

NREL 11.9 Natural Gas Engine Project

- Funding partners:
  - NREL (with funding from DOE, CEC's PIER program, and AQMD)
  - CEC AB118 program (in conjunction with Gas Technology Institute)
- Dovetails into prior CEC PIER project, conducted in conjunction with Gas Technology Institute
  - PIER project status reported at NGVTF 2010

- Project Objectives
  - Continue the 11.9 liter heavy duty natural gas engine development, building on the success of the CEC PIER-sponsored preliminary development work
  - Demonstrate a number of engines in a variety of on-road operating conditions to identify and resolve engine issues prior to commercial launch
  - Allow key customers to demonstrate the engine
  - Obtain emission certification at or below EPA / CARB emission standards
  - Prepare for high-volume commercial launch with OEM availability in a range of industry-leading Class 8 truck & tractor models by 2013

ISX12 G - Field Demonstration

- CWI deployed 25 field test trucks, plus additional “market seed” units, powered by pre-production Alpha & Beta engines

State	# Field Test Trucks	Comments
California	6	
Utah	5	Base for trucks operating interstate
Indiana	4	Includes CWI-operated Engineering trucks
Arkansas	2	De-commissioned and re-powered to diesel during field test due to oilfield contractor losing their contract and re-locating entire fleet to a different state, without CNG access.
Nebraska	2	Base for trucks operating interstate
Texas	1	
Arizona	1	
Wisconsin	1	Base for trucks operating interstate
New Jersey	1	
Oklahoma	1	
Various	1	OEM demo truck; operated in multiple states

- ~2.5 million miles of vehicle operation from the field test fleet
- Test engines have been removed new, emission-certified, production-built ISX12 G engines installed

Project Summary

- ISX12 G engine launched in 2013
  - Limited Production Apr-Jul (350 hp max rating)
    - Continued development of engine, calibrations & cylinder head to ensure we met all quality milestones with the 385 & 400 hp ratings
  - Full Production with full range of ratings (320 to 400 hp) began in August
  - Most successful NG engine launch in CWI's history
- CWI / NREL Subcontract expired Dec 31, 2013
  - Final report submitted to NREL in December
- ISX12 G development program has been a huge success. CWI continues to anticipates strong sales demand.

- Thank you to CEC, DOE, AQMD & NREL program management and staff for supporting this project.

ISX12 G

Natural Gas Engine

- **Key Product Attributes**
  - 4 cycle, spark ignited, in-line 6 cylinder, turbocharged, CAC
  - Displacement – 11.9 litres (726.2 cu in)
  - Peak rating: 400 hp, 1450 lb-ft
  - 2014 EPA/CARB certified
  - Meets 2014 EPA GHG requirements
  - Dedicated 100% natural gas engine
    - Will operate on CNG or LNG
  - Three Way Catalyst after-treatment
  - Engine braking
  - Manual/Automatic /AMT Transmissions

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Customer Feedback

John Erwin
Director of Operations Support

Saddle Creek TRANSPORTATION

- ISX12 G does everything we need it to do..from city delivery to 80,000 lb class 8 highway transport.
- Our commitment to natural gas has brought new business our way

Carl Suhr
Kwik Trip

KWIK TRIP

- Fuel economy is currently running 12-13% per DGE below our diesels in like application. That being said, our average cost differential between diesel and CNG is running at a 48% advantage for CNG. Due to this differential our fuel CPM is dramatically improved with the CNG equipment.

Mark Storemann
Director of Operations

ampCNG Fueling the Future of Trucking

Our 42 - ISX12 G Kenworth T660 Ruan trucks at Fair Oaks farm have accumulated about 72,000 miles/truck, and the fuel economy has been 5.8 - 6.0 mpg., which is 12% better than our ISL G fleet."

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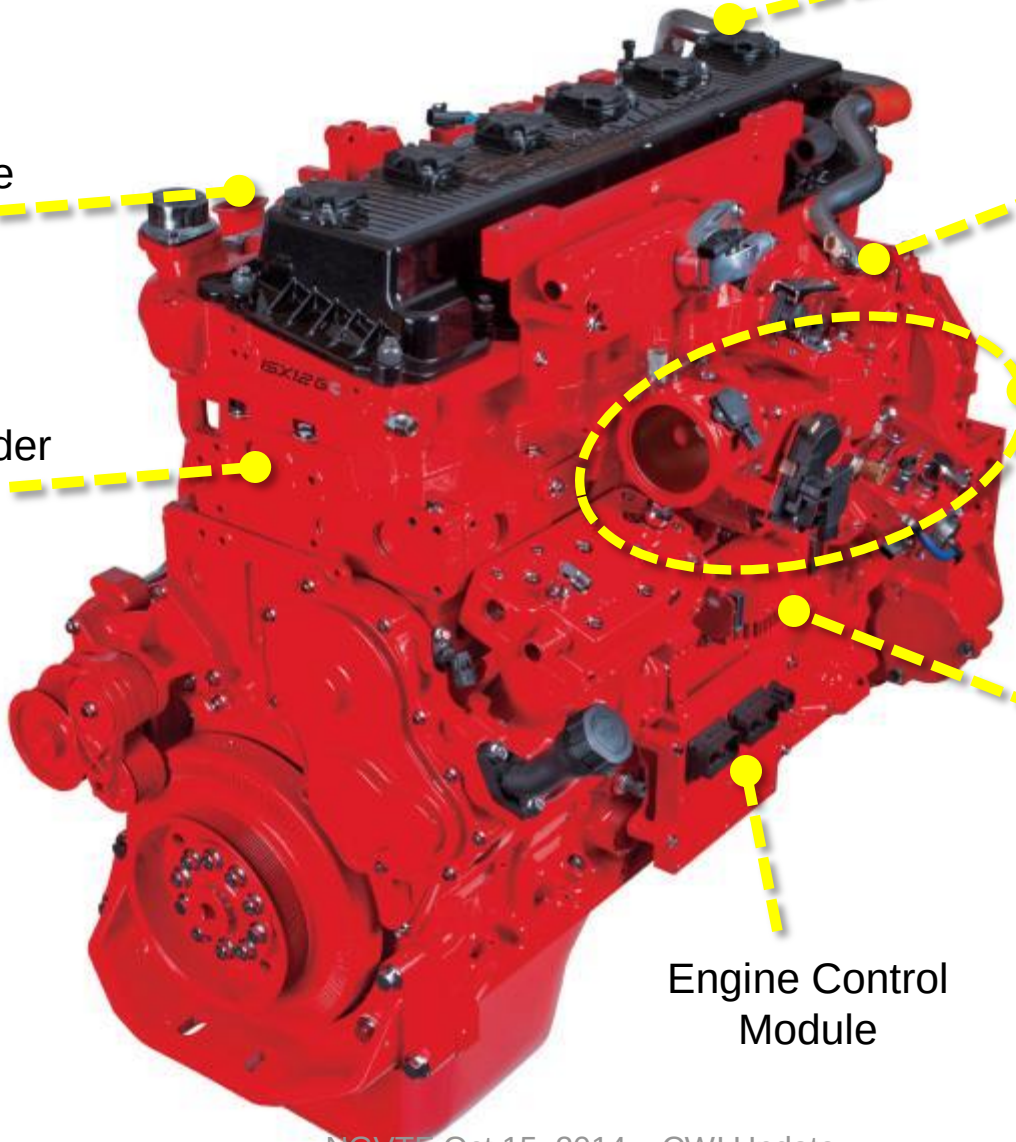
ISX12 G Design Architecture



ISX12 G Availability

OEM	Freightliner	Peterbilt	Kenworth	Volvo	Mack	Autocar
						
Model	Cascadia Day Cab, **Sleeper *** **114SD****	320 384 365 **579 *** **567***	W900S T660 T800 SH **T680 ***	VNL	Pinnacle	Xpeditor
Engine	ISX12 G	ISX12 G	ISX12 G	ISX12 G	ISX12 G	ISX12 G
Application	Tractor	Refuse Tractor Vocational	Tractor Vocational	Tractor	Tractor Vocational	Refuse

CNG LNG

*New chassis for 2014

** New chassis for 2015

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New Model Announcements - 2014

Kenworth T680

The T680 was introduced in day cab and 76-inch sleeper configurations, and a 52-inch mid-roof sleeper option was added last year.

Peterbilt Model 579

Peterbilt Model 567

Peterbilt introduced the on-highway Model 579 and the vocational Model 567 ideal for customers in short- and regional-haul, refuse and construction applications.

Freightliner Cascadia Sleeper

Freightliner Cascadia® natural gas-powered tractor available with a 48-inch sleeper cab, and factory-installed compressed natural gas (CNG) or liquefied natural gas (LNG) tanks

Freightliner 114SD

Freightliner 114SD severe duty available in 2015 with the ISX12 G.

Peterbilt Model 579

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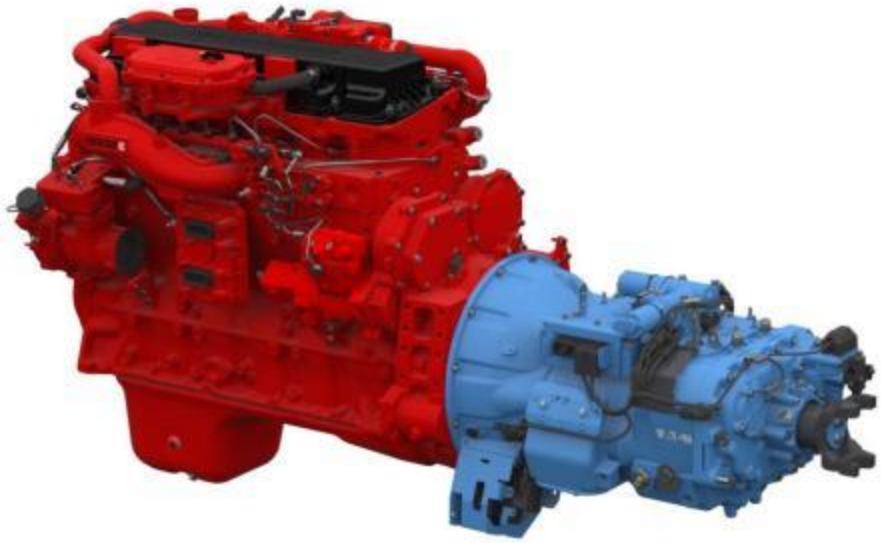
ISX12 G with UltraShift PLUS

- Eaton approved package
- For Linehaul Active Shifting (LAS) and Multipurpose High Performance (MHP) transmission models
- Linehaul and Regional Haul only



ISX12 G

UltraShift Plus Availability

OEM	Available?	Timing
KENWORTH	Yes	Now
Peterbilt	Yes	Now
VOLVO	Yes	TBD
MACK	Yes	TBD
FREIGHTLINER	Yes	TBD

Status: June 2014

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2014/16 Cummins Westport Products.

ISB6.7G

6.7 Litre

Spark Ignited
SEGR
Three Way Catalyst

ISL G

8.9 Litre

Spark Ignited
SEGR
Three Way Catalyst

Up to 60,000 miles/year
66,000 lb. GVW

ISX12 G

11.9 Litre

Spark Ignited
SEGR
Three Way Catalyst

Up to 80,000 lb. GVW

CNG LNG

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Questions